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Growth Rates and Age Estimates of *Alsophila setosa* Kaulf. in Southern Brazil

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Abstract.—The tree fern *Alsophila setosa*, occurs in primary and secondary forests of southern and southeastern Brazil. Two populations in secondary forest formations in the northeastern part of the State of Rio Grande do Sul, in the municipalities of Morro Reuter (45 plants) and Sapiranga (48 plants), were studied to estimate the ages of the plants. Two approaches were tested, one based on the total length in relation to the yearly growth rate of the caudex, and the second on the total number of scars and remains of stipe bases along the caudex in relation to the yearly frond production. Estimates based on growth rates and total length did not agree with the information and records of the past land use, whereas frond production over a longer time period presented acceptable estimates. The development of a new plant formed through vegetative reproduction was observed during three years. A brief discussion of the problems of age estimates in tree ferns is presented.

Biological data are urgently needed for conservation efforts of endangered species such as tree ferns subject to commercial exploitation. Some species are the source of fibrous material formed by the adventitious root mass covering the caudex which is used for growing orchids and aroids, while others have plants removed from the field and used in landscaping and decoration. Even with adherence to the CITES agreements restricting the trade, local use still represents a major pressure for conservation. Forest management plans tend to exclude tree ferns or inflate the information on their growth and regeneration potential, while the concerned protection agencies lack proper information on their growth rates. A better understanding of the role of tree ferns and the presence of some epiphytic species is still urgently needed. In some cases, as discussed by Coomes *et al.* (2005), tree ferns offer conditions for the germination and initial establishment of some woody vascular seed plants, thus having an important role in their regeneration.

Tree ferns present some interesting biological aspects, growing many meters tall, sometimes up to the forest canopy, while presenting only primary tissue and a water supply through tracheids. Their growth, compared to some woody plants can be considered slow, but the lack of more precise field data constitutes a major problem in establishing the age of individual plants. Ages of tree ferns tend to be estimated using a) the total caudex length in relation to the yearly growth rates or b) the yearly frond production in relation to the total number of frond vestiges (old fronds, remains of stipe bases or scars) along the caudex. The first method assumes that the growth is constant throughout the life-span, while the initial stages, from the formation of the young sporophyte on the gametophyte are left out from the estimates. The second method cannot be applied to all arborescent species without serious damage to the plants (leaf scars covered by adventitious roots and/or remains of stipe bases) while the initial development, up to plants presenting a definite caudex with leaf scars, is also left out of the estimates.

Age estimates based on the total caudex length and yearly growth rates were presented by Conant (1976) for Cyathea *arborea* (L.) Sm. and *Alsophila bryophila* R. M. Tryon, growing in Puerto Rico; Ortega (1984) for *Sphaeropteris senilis* (Klotzsch.) R. M. Tryon, in Venezuela; Bittner & Breckle (1995) for *A. erinaceae* (H. Karst.) D. S. Conant, *A. polystichoides* (H. Christ) Domin, *C. delgadii* Sternb., *C. nigripes* (C. Chr.) Domin, *C. pinnula* (H. Christ) Domin and *C. trichiata* (Maxon) Domin, in Costa Rica.

Seiler (1981) estimated the age of *Alsophila salvinii* Hook., in El Salvador based on the frond production and the scars along the caudices, pointing out that the exact age could not be established as the frond production rate of very young plants is not known. Tanner (1983) using the same basic method estimated the age of *Cyathea pubescens* Mett. *ex* Kuhn plants growing in Jamaica. Ash (1987) estimated the age of *C. hornei* (Baker) Copel. plants in Fiji, including more information on the spacing of the frond scars.

Walker & Aplet (1994) presented age estimates and information on the growth response of the caudex of *Cibotium glaucum* (J. Sm) Hook. & Arn. after the addition of nutrients, noting that Nitrogen or Phosphorous increased the growth rate. These authors also verified that the caudex has higher growth rates in 1000 year old forest plots, when compared to that of younger forest formations. Durand and Goldstein (2001) evaluated relative growth rates and the reproductive potential in native (*Cibotium* spp.) as well as invasive (*Sphaeropteris cooperi* (Hook. *ex* F. Muell.) Tryon) tree ferns in Hawaii and verified that the invasive species presents a more intensive growth. Arens (2001) studied growth rates of *Cyathea caracasana* (Klotzsch.) Domin, at different sites in Colombia, under differing ecological conditions and distinct regeneration stages.

Among the tree ferns used for landscaping and decoration in the State of Rio Grande do Sul, Brazil, *Alsophila setosa* Kaulf. (Cyatheaceae) is currently being extracted from forest remnants (Windisch, 2002). The existing populations are also being reduced by deforestation for lumbering and use of the land for grazing or agriculture (Schmitt and Windisch, 2005). This species grows in primary and secondary humid forests in South and Southeastern Brazil, between 20 m and 1800 m elevation. In southern Brazil it occurs also in forests with *Araucaria* and *Podocarpus* as well as humid places in semi-deciduous forest formations. The plants grow up to 10 m tall, have a caudex ca. 10 cm in diameter (Gastony, 1973), with remains of stipe bases (with blackish spines) on the distal part and frond, and scars (from fallen fronds) on the basal portion. The crown is up to 3 m long and has fronds with tripinnate-pinnatisect laminae (adult plants). Considering the lack of biological data for *A. setosa*, as well as the need for more knowledge of tree fern development, growth rates and comparative age estimations based on different approaches are being presented.

Material and Methods

Fieldwork was conducted in two semi-deciduous seasonal broadleaved forest formations in the northeastern part of the State of Rio Grande do Sul, Brazil. The first site is located within the municipality of Morro Reuter (29°32′ S, 51°04′ W, alt. 700 m) and consists of a forest remnant surrounding a spring that is still in use as a local water supply, being protected from cattle and from deforestation (confirmed by local residents). The area is surrounded by less homogeneous secondary growth. The second site, at the municipality of Sapiranga (29°38′ S, 51°00′ W, alt. 570 m), is situated on an abandoned field that was in agricultural use up to the early 1960s. An aerial photograph of the region shows that this particular area was devoid of tree cover as late as December of 1964, so that the current secondary forest stand at the time of the observations was less than 40 years old. The selection of two populations was made without intending comparative analyses between the two populations, but basically in order to guarantee results even if predatory extraction of ferns or lumbering resulted in the loss of one of the populations during the course of the study.

Basic soil analysis (NPK) of samples from both localities was performed at the Geosciences Laboratory of the Universidade do Vale do Rio dos Sinos. Voucher specimens were placed at the Universidade do Vale do Rio dos Sinos Herbarium (HASU 10176; HASU 9773).

The climate is humid sub-tropical (Teixeira *et al.*, 1986), and data from the nearest meteorological station (Ivoti, 127 m alt) indicate an average mean temperature of the coolest month of 13.3°C (July), average of the warmest month of 25.1°C (February), absolute minimum −1°C (July) and absolute maximum 35.7°C (September and January) during the study period. Total precipitation was 2138 mm, the driest month being May (40.9 mm in 2000 and 78 mm in 2001), with maximum rainfalls in September (232.2 mm), October (303.9 mm), and January (308.6 mm). Data for an extended period of time could not be obtained. Frost occurs several times during more intense winters.

Two approaches were used to estimate the age of the plants. One was based on the relationship between the average yearly growth rate in height and the total length of the caudex. The second was based on the relationship between the average number of fronds produced during the year in relation to the total number of fronds along the caudex, as determined by counting fronds and their vestiges (remains of stipes and scars left by the fronds after complete decomposition of the stipe bases).

For frond production analysis, plants up to 4 m tall (the maximum size that safely could be reached in order to follow the frond production at the apex) were marked by placing wooden stakes with aluminum labels in the ground close to the base of each caudex. Larger plants with caudices up to 4.7 m tall can be found in the sites, but were not studied. At Morro Reuter 45 plants were marked and another 48 at Sapiranga. Each caudex with a crown of fronds was considered to be an individual. Caudex length was measured from the ground surface to the extreme apex at the center of the crown of fronds.

Initial field observations of frond production were conducted from May 2000 to April 2001, with the height of the caudices registered at the beginning and end of this period. Annual frond production was determined by marking (with a loose loop of synthetic fiber) the youngest expanding crozier on each marked plant at the beginning of the observation period, this serving as a reference for recognizing the new fronds produced during the study period.

In order to estimate the total numbers of fronds produced at each site, 10 individuals were sampled, leaving out plants with caudices less than 40 cm tall and taller than 3.5 m; the latter were mostly covered by adventitious roots or epiphytes making counting impossible. When a part of the caudex presented patches of epiphytic cover, the average between the preceding and the next 20 cm sections was used as an estimate of the number of scars present underneath the covered part.

In August 2003, additional data set were collected from nine caudices in each population, removing all the epiphytes in order to obtain a precise count of the total number of stipe bases and scars. This also allowed the verification of caudex growth in length and frond production over a three-year period. On that occasion, the development of a young plant, which in October 2000 was sprouting out of the ground close to one of the marked specimens, was evaluated. This new individual started out from a well developed crozier, emerging from the soil and clearly was not a small plantlet formed from a gametophyte.

Pearson's correlation test was used to evaluate the relationships between the length of the caudex and the total number of scars and stipe bases, the length of the caudex, and the yearly frond production. Linear regression analysis was used to estimate the number of stipe bases and the yearly frond production relative to caudex length. In the second approach, the age estimate resulted from the equation: total number of fronds and vestiges / yearly frond production rate.

Data analysis was performed as described by Vieira (1980) and Zar (1999) using the SPSS 9.0 program installed at the Universidade do Vale do Rio dos Sinos data processing facility.

Results

During the 12 month period the average caudex growth rate based on the samples from Morro Reuter was 14.51 (s.d. = $\pm$11.49) cm.yr^{-1}, ranging from a maximum rate of 47 cm.yr^{-1} to three individuals with no noticeable growth as (although new fronds were formed). In Sapiranga the average growth rate was 6.32 (s.d. = $\pm$5.53) cm.yr^{-1}, with a maximum growth of 22 cm.yr^{-1} and ten plants showing no noticeable length increase. The growth rates of these populations were significantly different ($P < 0.001$). There was no significant

TABLE 1. Comparative age estimates of an *Alsophila setosa* plant with a 4 m long caudex, using the one year data (n = 45 for Morro Reuter, n = 48 for Sapiranga).

Locality	Growth rate	Estimated age based on growth rate	Age based on frond production equation
Morro Reuter	$14.51\ cm.yr^{-1}$	27 years	22 years
Sapiranga	$6.32\ cm.yr^{-1}$	63 years	32 years

correlation between caudex growth and total length in Morro Reuter (r = 0.258, P = 0.086, n = 45) or in Sapiranga (r = 0.166, P = 0.253, n = 48).

A strong positive correlation between the length of the caudex and the number of scars and stipe bases was observed both in Morro Reuter (r = 0.856, P = 0.02, n = 10) and in Sapiranga (r = 0.825, P = 0.03, n = 10). The yearly frond production also showed a strong positive correlation with caudex length both in Morro Reuter (r = 0.845, P = 0.02, n = 10) and Sapiranga (r = 0.876, P = 0.01, n = 10). Based on these strong direct correlations, a linear regression analysis was performed in order to obtain equations to estimate the number of scars per total caudex length and to predict yearly frond production. The number of scars/stipe bases in relation to the length of the caudex (H), in Morro Reuter was estimated as: $y = -12.115 + 0.9H$ and the yearly frond production by $y = -0.773 + 0.042H$. In Sapiranga the equations were respectively $y = 47.149 + 0.577H$ and $y = -0.0138 + 0.0218H$.

Approximate age estimates for hypothetical plants with 4 m long caudices using the first approach (total caudex length divided by the average growth rates) are presented in Table 1. In the case of the Sapiranga site, the resulting age estimate does not agree with the age of the forest.

For estimating age based on the total number of fronds in relation to the yearly frond production, for Morro Reuter plants the formula would be $(-12.115 + 0.9\ H)/(-0.773 + 0.042H)$, whereas for Sapiranga it would be $(47.149 + 0.577H)/(-0.0138 + 0.0218H)$. These results indicated lower ages than those using the first approach (Table 1).

The analysis of the preliminary data indicated that a bias was introduced by the variation in growth pattern during the initial phases of development. Also the frond production rate in a particular year does not reflect the average growth conditions throughout the life span of a given plant. This led to a new survey of the marked plants still standing in the localities in August 2003. Data for caudex length and number of scar/stipe bases were obtained for a three year period for nine plants in each population. The sampled plants in Morro Reuter produced an average 8.66 $fronds.yr^{-1}$ while those from Sapiranga 6.92 $fronds.yr^{-1}$. Age estimates based on these data for 4 m tall hypothetical plants are shown in Table 2.

As to the basic nutrients in the soil, no significant differences in NPK were found between populations based on t-tests (Nitrogen: P = 0.981, Phosphorous: P = 0.440 and Potassium: P = 0.282). Samples within each site did show heterogeneity among collecting points.

TABLE 2. Age estimates using the total number of fronds produced in two plants with 4 m tall caudices and the average (n = 9 in each population) yearly frond production (3 year period).

Locality	Scars/stipes in a 4 m long caudex	Average yearly frond production (3 years)	Estimated age
Morro Reuter	244	8.66 fronds·yr^{-1}	28 years
Sapiranga	238	6.92 fronds·yr^{-1}	34 years

The rapid growth of vegetatively produced plants is illustrated by the single individual, initially observed in October 2000 at the Morro Reuter site, represented by a crozier emerging from the ground. In February 2001 its caudex was 7 cm. By April it had reached 10 cm and bore a crown of ca 3.5 m diameter with fronds up to 230 cm long. By September 2003, this plant had a 70 cm long caudex.

Discussion

The average growth rates observed for *Alsophila setosa* are within the range of growth rates reported by other authors for other species of the genus (Table 3). The "no noticeable" growth status of some plants with reduced caudex growth may be due to the presence of unexposed young croziers (still covered by a mass of scales) at the tip of the caudex at the time of the first measurement. The differences in the growth rates between sites, in the present study, could be related to different canopies and different successional stages of the surrounding vegetation. Arens (2001) presented some interesting data on *Cyathea caracasana*, growing in different habitats in Colombia, indicating a life history with periods of rapid growth, spore production, and establishment in forest gaps, alternating with low growth rates and persistence in the understory, and recorded higher growth rates in open habitats.

Slightly lower growth rates were observed in Sapiranga, where the forest is younger and the upper canopy more continuous. *Alsophila setosa* is an understory plant, so that the height of the canopy seems to influence the height increase once the fronds reach that level. In our experience, this species never

TABLE 3. Growth of the caudex in different species of the genus *Alsophila*.

Species	Growth rate (cm·yr^{-1})	Locality	Forest	Source
Alsophila bryophila	5.0	Porto Rico	Primary	Conant (1976)
Alsophila salvinii	6.9	El Salvador	Secondary	Seiler (1995)
Alsophila erinacea	13.6	Costa Rica	Primary	Bittner & Breckle (1995)
Alsophila polystichoides	18.8	Costa Rica	Primary	Bittner & Breckle (1995)
Alsophila setosa	14.51	Brazil	Secondary	Present study
Alsophila setosa	6.32	Brazil	Secondary	Present study

surpasses the upper tree canopy. Also different heights of the crown of fronds may lead to differences in exposure to low temperatures. Frost damage to young croziers has been reported by Schmitt and Windisch (2001). Although the macro-nutrients (N, P, K) did not show significant differences, considering the different histories of soil usage in both plots, differences in micronutrients may occur between the study sites.

Considering the aerial photograph taken in 1964 of the area in Sapiranga site, the estimate of 32–34 years for the taller plants is much more realistic that the one obtained only using the yearly growth rate (63 years). The use of the frond production data, especially if obtained over a longer period of time, produces acceptable values (compare Tables 1 and 2). This would mean that the tallest plant at the locality (4.7 m) would be about the same age as the forest stand.

However, using the formulas applied in the example in Table 1 to a plant taller than 4 m the resulting age would have lower value than the one obtained for a 4 m plant, as the sample includes a larger number of younger plants with different growth patterns. Attempts to exclude this bias were not successful due the size of the samples in the different age brackets of the studied plants, and surely also due to differences in their initial stages of development. Tanner (1983) indicated that the method using total number of fronds in relation to the yearly frond production gives more realistic values for growth in plants of lower stature, but less realistic values for caudices greater than 1 m tall.

Two of the variables affecting these estimates is the time needed to establish the sporophyte from spore and the growth up to the stage where a caudex with noticeable scars is formed and preserved throughout the life of the plant. Another variable is the reproductive origin of the plants. In species such as *Alsophila setosa*, with both vegetative and sexual reproduction, age estimates may differ for stems produced by the two reproductive modes. The rapid growth of the vegetatively formed individual is striking and indicates a strong potential for leaving the shaded ground cover by the rapid development in the first stages of these plants.

Based on the yearly frond production rates and the total frond vestiges on the caudex, Seiler (1981) estimated the age of 4.6 m tall *Alsophila salvinii* sporophytes at 55 years; Tanner (1983) estimated *Cyathea pubescens* with 9 m tall plants at 150 years old; Ash (1987) estimated 5.5 m tall plants of *C. hornei* as being between 80 and 105 years. The following age estimates based on yearly growth rates and total length of the caudices may be found in the literature: *Alsophila bryophyla*, 5 m tall, 5 $cm.yr^{-1}$ growth in length, considered to be 100 years old; *Cyathea arborea*, 5 m, 28.6 $cm.yr^{-1}$, 18 years (Conant,1976); *Sphaeropteris senilis*, 2 m, 4 $cm.yr^{-1}$, 50 years (Ortega, 1984); *A. erinacea*, 5 m, 13.6 $cm.yr^{-1}$, 37 years; and *A. polystichoides*, 5 m, 18.8 $cm.yr^{-1}$, 27 years (Bittner and Breckle, 1995).

There is a lack of field data on the first stages of gametophytic and sporophytic development for these species resulting in a poor understanding of the complete life cycle. The extraction of plants for cultivation represents the removal of material that may take decades to be formed, and the original growth conditions for gametophytes and young sporophytes may no longer be available in the site. However, in species with vegetative propagation, such as *Alsophila setosa*, new individuals produced in this manner may occupy the available niches and perpetuate the presence of the species. These young individuals plants after a rapid growth through the herbaceous layer, become part of the stand, and many of the smaller plants considered in the present study probably had this origin. This presents additional problems for age estimates because we may not be differentiating between sporophytes of different origins and different growth characteristics.

Our data suggest that some of the previously published age estimates should be reconsidered, taking into account the different methods and problems outlined above. Longer observation periods, especially in areas of less uniform climates are highly desirable. In general, our growth rate results are similar to those for other species of tree ferns in different regions, especially those of *Cyathea caracasana* (Arens, 2001) *Alsophila bryophila* (Conant, 1976), *A. salvinii*, *A. erinacea* and *A. polystichoides* (Bittner and Breckle, 1995).

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